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13. ABSTRACT *(Maximum 200 words)*
We have developed a fully characterized pulsed eddy current (PEC) instrument to detect and characterize "second-layer" corrosion in aircraft skin. In the first year, we developed the theory needed to accurately model the response of the PEC instrument measured on a variety of calibration specimens. In the second year, we made experimental measurements on a number of realistic samples including a corrosion test panel provided by Boeing corporation. In addition, inverse methods were developed for estimating the location and amount of hidden corrosion. In the third year, the inversion methods were fully incorporated in the PEC instrument. New methods were developed: (1) for calculating the response due to pitting corrosion; and (2) for removing interfering signals from fasteners and other structures. The experimental effort in the third year focused on technology transfer. The instrument was a highly successful participant in the Air Force blind trials for corrosion detection and characterization (carried out by ARINC corporation). The PEC instrument and its capability for the quantitative detection of hidden corrosion was demonstrated in visits to the Air Logistics Commands at McClellan, Kelly and Warner Robbins AFB's. Finally, the PEC instrument along with the quantitative analysis module was licensed to Sierra Matrix, Inc. of Fremont, California.

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Nondestructive Detection and Characterization of Corrosion in Aircraft

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Final Report:

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Objectives:

To detect and characterize corrosion in aircraft.

There are two inspection modalities being developed: pulsed eddy-currents and energy-resolved x-ray backscatter. Each modality has separate objectives:

Pulsed Eddy-Currents: To develop the theoretical and experimental basis needed for a fully characterized pulsed-eddy current (PEC) instrument to detect and characterize "second-layer" corrosion in aircraft skin. To develop the theoretical tools needed to detect and characterize corrosion in the second layer of aircraft skin using pulsed eddy-current measurements. To perform the experiments needed to validate the key insights developed in the theoretical effort.

Energy Resolved X-rays: To investigate the feasibility of novel x-ray based energy sensitive inspection and material characterization techniques for the detection and evaluation of the extent of hidden corrosion in aluminum aircraft structures. Special attention will be given to the development of an energy dispersive material characterization capability for single sided x-ray inspections.

Summary:

Pulsed Eddy-Currents:

We have developed a fully characterized pulsed eddy current (PEC) instrument to detect and characterize "second-layer" corrosion in aircraft skin. In the first year, we developed the theory needed to accurately model the response of the PEC instrument measured on a variety of calibration specimens. In the second year, we made experimental measurements on a number of realistic samples including a corrosion test panel provided by Boeing corporation. In addition, inverse methods were developed for estimating the location and amount of hidden corrosion. In the third year, the inversion methods were fully incorporated in the PEC instrument. New methods were developed: (1) for calculating the response due to pitting corrosion; and (2) for removing interfering signals from fasteners and other structures. The experimental effort in the third year focused on technology transfer. The instrument was a highly successful participant in the Air Force blind trials for corrosion detection and characterization (carried out by ARINC corporation). The PEC instrument and its capability for the quantitative detection of hidden corrosion was demonstrated in visits to the Air Logistics Commands at McClellan, Kelly and Warner Robbins AFB's. Finally, the PEC instrument along with the quantitative analysis module was licensed to Sierra Matrix, Inc. of Fremont, California.

Energy Resolved X-rays.

The activity over the last three years supported by the AFOSR in energy dispersive backscatter detection of corrosion in complex geometry's resulted in a number of advancements. The first year was devoted to developing a backscatter camera using CdTe detectors positioned in a ring around the incident beam. The initial design of the camera was for the use of an Am 241 isotope source. The final conclusion of the isotope source camera showed that these sources produce too little flux to acquire backscatter signals in a

reasonable time, i.e. less than one hour. The second year began by modifying the backscatter camera to accept an x-ray generator source. Bremsstrahlung sources are 10^4 times brighter that isotope sources. The modifications included a mounting mechanism and a beam monitor. The beam monitor is required as the intensity of typical x-ray tube sources fluctuates over time. The backscatter camera coupled to the tube source proved successful in measuring metal loss in several layers of aluminum skin. The backscatter signals from layered structures, especially when a rib and three or four skin layers, proved to be very complex. To interpret these signals we developed a model of the backscatter process. This model built on the previous base of x-ray radiography modeling developed at the Center for NDE at ISU. The backscatter model provides a means of understanding collimation, source/sample interaction and the effect of part geometry. To incorporate the complex part geometry's, we coupled the backscatter model to the CAD representation of the part geometry. The result, BKSIM, is a flexible backscatter model for determining the effect of scan parameters on the type and size of the backscatter signal. In the third year we began to develop an extensive library of corrosion samples. These samples were produced in the corrosion tank at ISU and included a large number of corroded regions in aircraft skin. The depth of the corrosion was varied to range from 1% to 50% with areas ranging from 0.25 cm^2 to 5.0 cm^2. The plates were then assembled into various structures. The amount of metal loss was measured with calibrated x-ray thickness gauging. Each of the samples was radiographed using a microfocus setup at 10X magnification. The resulting radiographs were digitized and converted into a map of remaining metal.

Accomplishments and New Findings:

A quantitative analysis module was developed and validated for the detection of hidden corrosion in aircraft panels using the PEC instrument. This analysis module was successfully tested in AF blind trials for the detection of corrosion and its quantitative analysis capabilities was demonstrated at several ALC's.

Pulsed Eddy-Currents:

Theory:

- Developed quantitative theory for the "forward" response of the PEC instrument based on first-principles treatment of the problem starting with Maxwell's equations.

- Developed quantitative "inverse" method that estimates the location and thickness of hidden corrosion.

- Developed a novel perturbation method for PEC instrument's response to pitting corrosion.

- Developed time-domain methods for distinguishing the effects of corrosion from interfering signals such as fasteners or other support structure.

Experiment:

- Made quantitative measurements with PEC instrument on laboratory specimens designed mimic the effects of corrosion.

- Tested the accuracy of the "forward" theoretical calculations and obtained excellent agreement.

- Constructed a new portable instrument to detect wall-loss in lap-splices under AFOSR funding based on a "lunch-box" portable PC

- Incorporated theoretical inverse methods based on "time-of-arrival" and obtained accurate answers.

- Demonstrated the ability to use time-domain information to distinguish hidden corrosion from interfering signals from fasteners and support structure.

- Successfully completed AF sponsored blind trials for corrosion detection.

- Demonstrated quantitative capability of portable instrument at ALC's

- Licensed PEC instrument to Sierra Matrix, Inc.

Energy Resolved X-rays:

- Evaluated use of isotope source in backscatter imaging - flux too low for useful times
- Constructed and tested a backscatter camera use CdTe solid state detectors
- Developed x-ray tube beam monitor and adapted camera for tube mounting
- Demonstrated energy dispersive backscatter measurement of corrosion in skin to 5% metal loss
- Developed a backscatter simulation model, source collimation, detector collimation, scattering mechanism, CAD part representation, scan generation
- Fabricated and characterized a large number of engineering corrosion samples
- Improved speed of energy dispersive data analysis by a factor of 140.
- Demonstrated the use of compact room temperatures energy dispersive detectors, CdTe and CdZnTe

Personnel Supported:

Principal Investigator: James H. Rose

Principal Investigator: John C. Moulder
Student: William Ward

Principal Investigator: Joseph N. Gray
Other Investigator Terrence Jensen
Student: Brian Hinzie

Transitions

The pulsed eddy-current instrument has been licensed for production to Sierra Matrix, Inc. of Fremont CA. The contact people are John Carruthers (510-623-3690) and the president of the company, Marv Flemming.

J. C. Moulder received funding for technology transfer of the pulsed eddy-current instrument from the FAA. The enabling research was the AFOSR task and prior work for the FAA. The contact individual at the FAA is Chris Smith.

New discoveries, inventions or patent disclosures:

A record of invention has been filed for the pulsed eddy-current instrument. This is the first step in seeking patent protection for this new instrument.

An energy-dispersive x-ray backscatter camera was invented and constructed.

Documents published in whole or in part with support of this grant.

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